Mosquito Bionomics -General Control Considerations

The American Mosquito Control Association (AMCA) has published a state of the art treatment of the principles and practices underlying an integrated approach to mosquito management (AMCA 2017). At its core, effective mosquito control depends on a comprehensive knowledge of the mosquito species to be controlled – its preferred oviposition habitat, its range, flight characteristics, feeding activity, temperature and humidity preferences, resting habits, and a bewildering variety of other considerations that must be taken into account when planning control operations. While there is considerable overlap in behavior among mosquito species, there are enough differences to make it imperative that they be taken into consideration in all effective mosquito control programs. A profound knowledge of mosquito bionomics allows programs to efficiently and effectively exploit the vulnerabilities of all life stages of the target mosquito population to maximize control while minimizing environmental impact.

Species distribution and dispersion limits are important factors in mosquito species identification and subsequent, effective control. According to Darsie and Ward (2005), there were 174 known mosquito species in North America. This has since been updated to currently reflect 182 species. Sixty-one species are confined to western states (with Texas, Arizona, and California having 7, 4, and 8 species, respectively, not occurring in any other state) and 17 species are confined to eastern states, 14 of which are limited to peninsular Florida. Not all known species are targeted in mosquito control programs because some species do not come into contact with humans, cause discomfort or carry disease. Mosquito control programs aim to minimize exposure by controlling species that negatively impact the quality of life and/or pose a health threat (have been identified as species of medical importance and are vectors or amplifiers (species maintains a very high level of disease parasites in blood) of disease of human or non-humans. Typically, most mosquito programs are primarily concerned with controlling only three or four mosquito species. Some of these species are daytime fliers found in floodwater habitats, breed in irrigation water, or are found in ponds and artificial containers. Others, such as, *Culex pipiens* which is considered to be responsible for transmitting the majority of West Nile Virus cases to humans, is primarily a night feeder and readily enters houses and other residential dwellings (WSDOH, 2007).

Potential Mosquito Vectors in the US

The mosquito species that have been identified as primary known or suspected vectors of pathogens to humans in the US are discussed below. This is not an exhaustive list but rather is intended to identify known or suspected vectors in the US that would most likely be the target of an adulticide program if a mosquito-borne disease outbreak, such as West Nile Virus, Dengue, St. Louis encephalitis, or malaria were to occur.

***Anopheles* species**

Anopheles mosquitoes are persistent biters and are the only mosquitoes which transmit malaria to man. As illustrated by the Malaria Atlas Project (MAP, http://www.map.ox.ac.uk) in Hay et al. (2009) there are very few potentially important and dominant vectors of human malaria in the US. These include *Anopheles freeborni* (Figure 1) in the western states, *An. quadrimaculatus* distributed throughout the eastern half of the US (Figure 2), and *An. pseudopunctipennis* which occurs in a few of the southern states (Figure 3).

Figure 1. Distribution of *Anopheles freeborni* (Darsie and Ward, 2005)

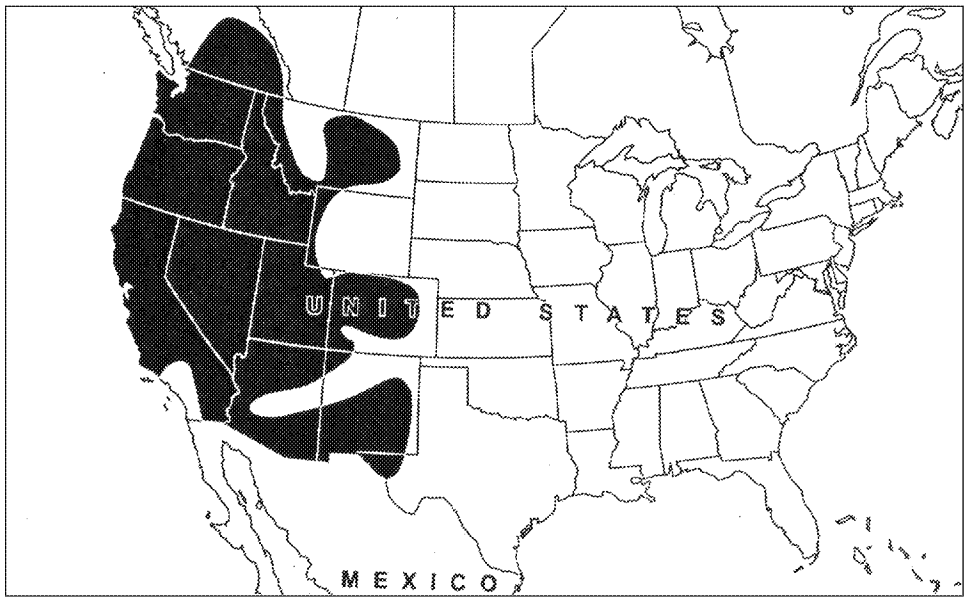


Figure 2. Distribution of *Anopheles quadrimaculatus* (Darsie and Ward, 2005)

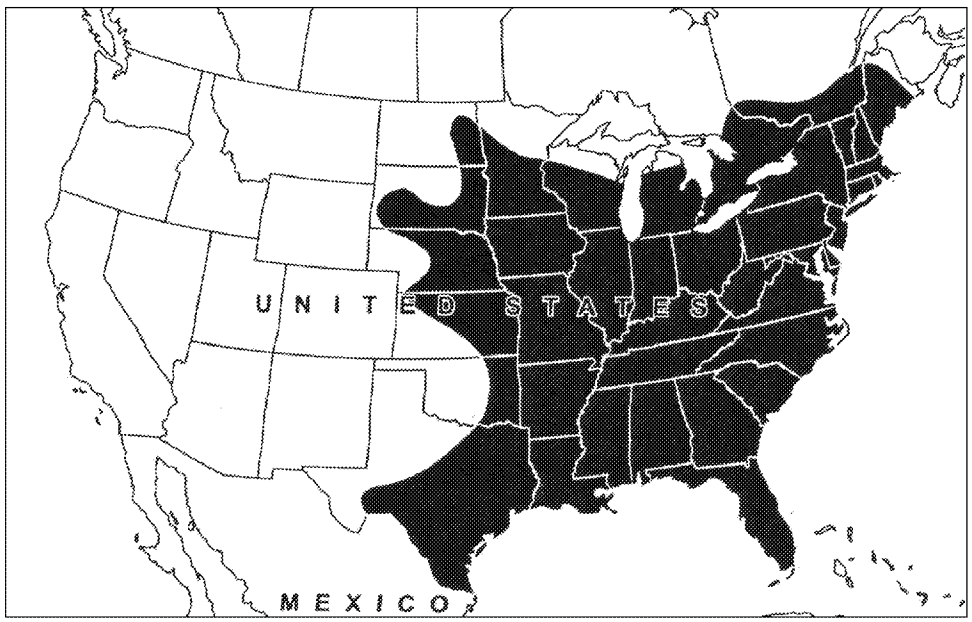
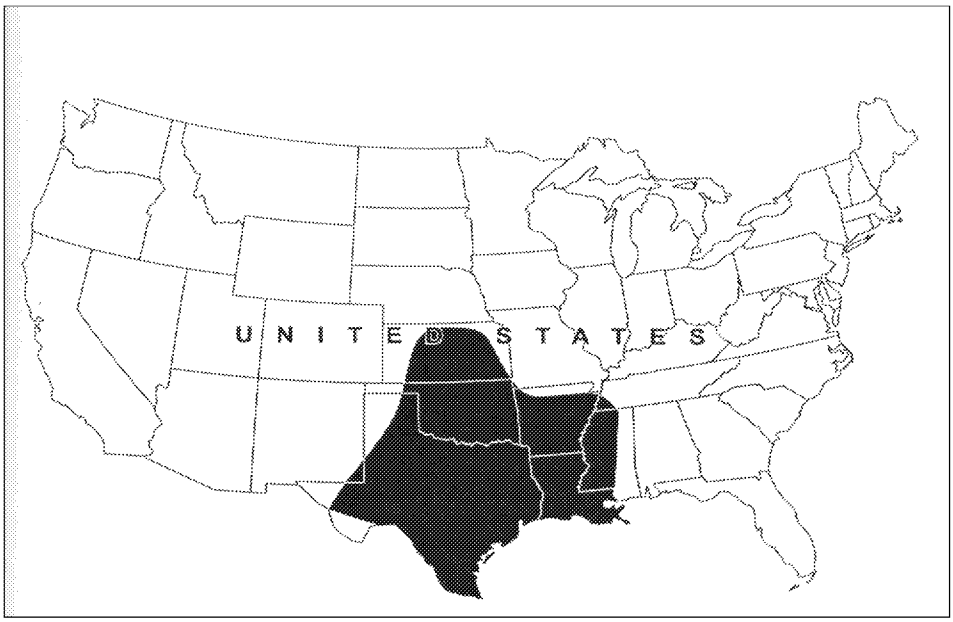


Figure 3. Distribution of *Anopheles pseudopunctipennis* (Darsie and Ward, 2005)



Anopheles larvae occur in a wide variety of habitats but most prefer clean, unpolluted permanent waterbodies and have been found in fresh or salt-water marshes, swamps, grassy ditches, rain pools, and rice fields. *Anopheles freeborni* and *An. franciscanus* larvae are typically found in rice fields and other clear, slow moving pools exposed to sunlight; in the eastern states, *An. quadrimaculatus* larvae are found in permanent and semi-permanent fresh water in streams, ponds, swamps, ditches, and lakes with emergent or floating aquatic vegetation (Carpenter and LaCasse, 1955; Goddard, 2003) and *An. pseudopunctipennis* larvae are typically found in sunny habitats including stream pools and margins that are highly associated with algae and vegetation (Manguin et al., 1996). Adult *Anopheles* are primarily mammalian feeders, typically feeding at dusk and dawn and will readily enter houses. During the day, adults rest inside dark buildings and shelters in dark corners, in hollow trees, stumps, and other sites that are convenient to egg-laying sites. The average flight range is one mile or less from production sites but can extend up to three miles (Carpenter and LaCasse, 1955; Goddard, 2003).

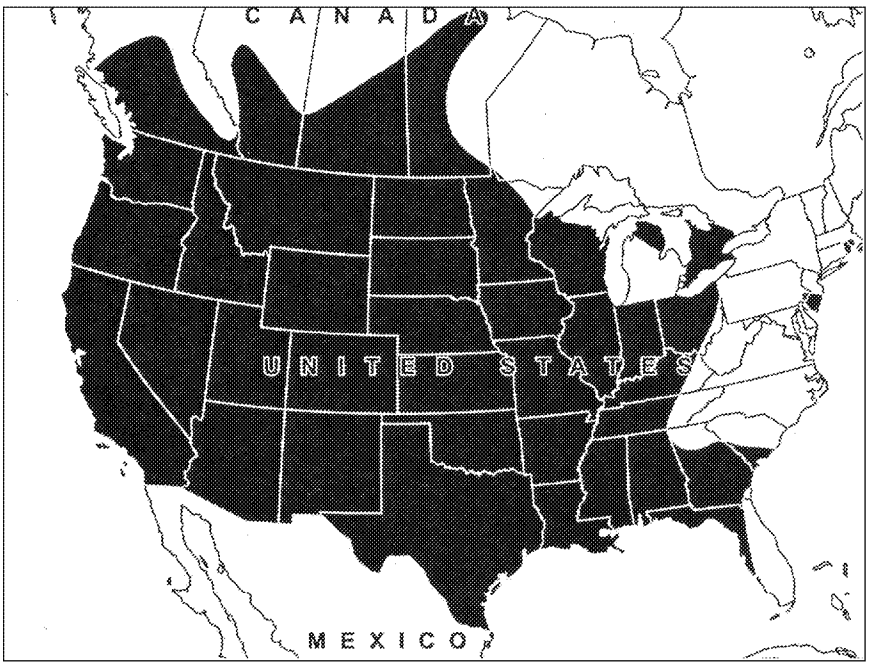
A malathion ULV use scenario that would likely result in the effective control of adult *Anopheles* would include application near households and residential areas to penetrate indoor resting areas as well as near and up to 3 miles from clean, water bodies representing potential egg-laying areas. These areas would not be near habitats of endangered species that live deep within forests and are surrounded by trees, cave-dwelling insects, and species located at very high elevation areas where residential and other dwellings are not established.

Culex species

Culex mosquitoes are painful and persistent biters and typically attack at dusk and after dark. They readily enter dwellings for blood meals but do not typically fly more than two miles from breeding sites.

Culex tarsalis is considered to be the most important vector of arboviruses in southwestern North America within irrigated and riparian habitats (Reisen, 1993; Figure 4) while the *Culex pipiens* complex is the most common species of concern along the Pacific coast and in Idaho.

Figure 4. Distribution of *Culex tarsalis* (Darsie and Ward, 2005)



Cx. tarsalis is commonly referred to as the irrigation mosquito because females lay eggs in newly-created, sunlit surface water pools generally surrounded by grasses and annual vegetation. A study conducted by Lothrop *et al.* (2002) found that adult *Cx. tarsalis* are more commonly found along elevated ecotones rather than flying over low vegetation, likely in search of a blood meal from birds. Also, adults found in abundance near emergence sites (i.e., surface water pools generally surrounded by grasses and annual vegetation) were blood fed or gravid whereas the majority of females found in upland orchards were unfed. Unfed females have not yet had a blood meal and are host-seeking; *Culex* spp. require a blood meal to develop mature eggs and it is during feeding when female mosquitoes take a blood meal from a host and have the potential to transmit a disease. A malathion ULV use scenario that would likely result in the effective control of adult *Cx. tarsalis* would include application to vegetative ecotones.

Mosquito species in the *Culex pipiens* complex are responsible for the majority of West Nile Virus isolations from field collected species in the eastern US (CDC, 2000) and responsible for

up to 80% of human West Nile Virus infections in the northeast (Kilpatrick et al., 2005). Also, species in this complex are the primary vectors of St. Louis encephalitis throughout the nation and dog heartworm in the south. Species in the *Cx. pipiens* complex are some of the most widely distributed mosquito species in the world. Within the US, this complex includes distinct species based on distribution; *Cx. quinquefasciatus* occurs at latitudes less than 36°N (Figure 5) and *Cx. pipiens* (Figure 6) is usually not found south of 39°N (Larrick and Connelly, 2009). Between 36°N and 39°N, these species overlap and often hybridize. Only in California is *Culex quinquefasciatus* and the hybrid species found well north of the 36th parallel (James and Harwood, 1969).

Figure 5. Distribution of *Culex quinquefasciatus* (Darsie and Ward, 2005)

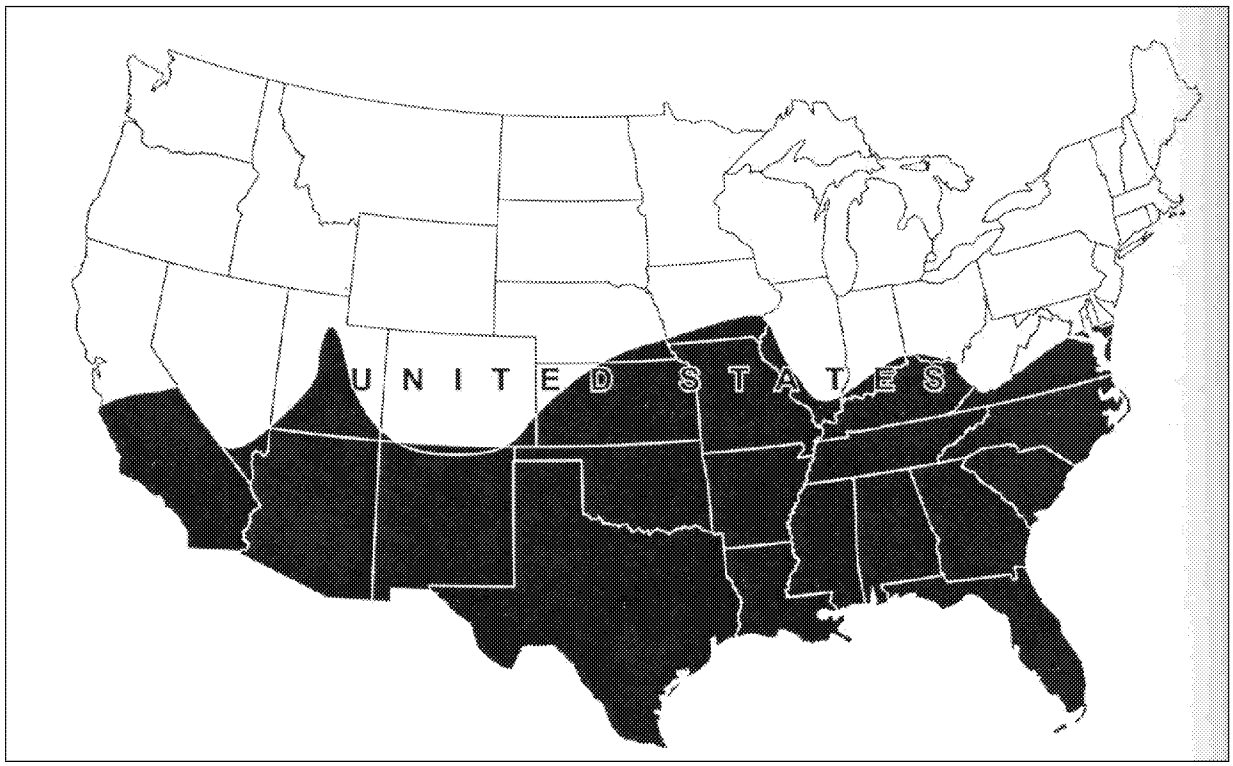
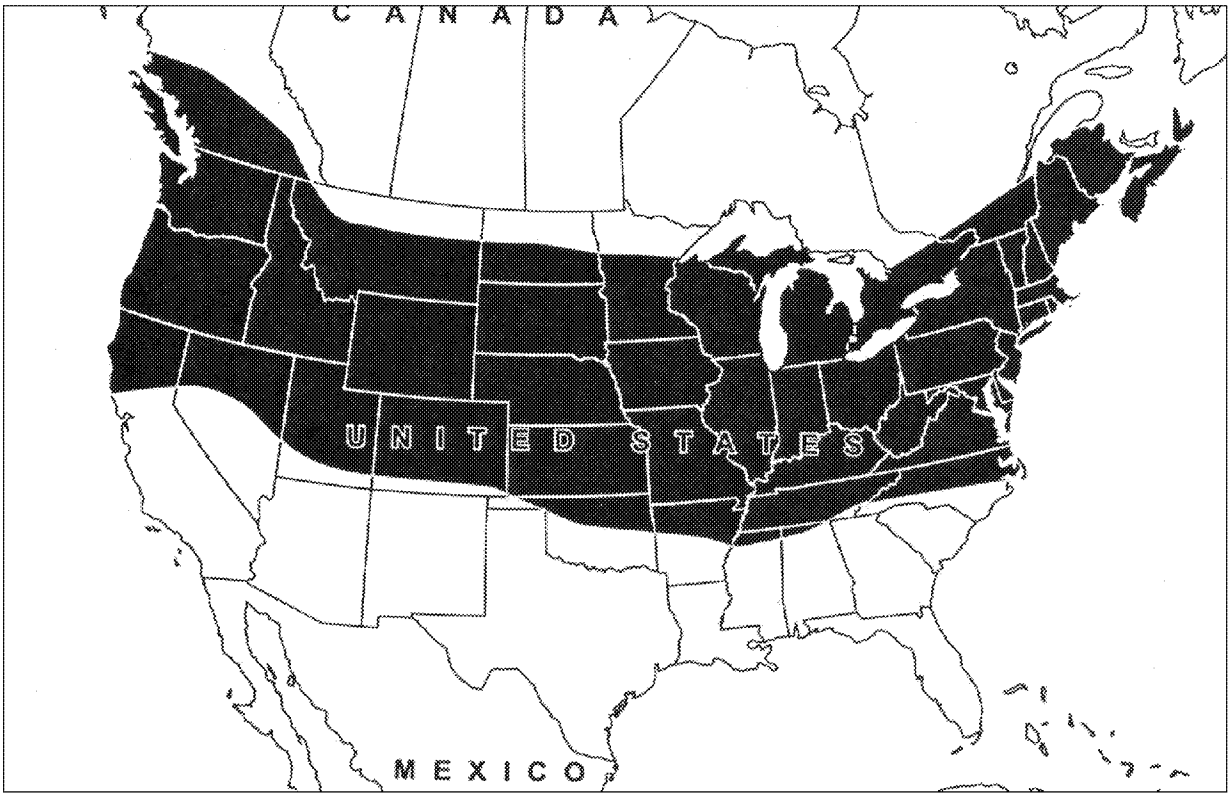


Figure 6. Distribution of *Culex pipiens* (Darsie and Ward, 2005)



As such, the habitats and life cycles of these species are similar. Females lay eggs in virtually any type of standing water, clean or polluted (polluted water is preferred), from waste water areas to any container holding water. Because eggs can develop in a wide variety of water containers, these species are common in urban and suburban communities and are often found in and around structures. *Cx. quinquefasciatus* is commonly called the southern house mosquito and is thought to be important in disseminating arboviruses from riparian habitats to adjacent residential habitats (Reisen *et al.*, 1992) and *Cx. pipiens* is commonly called the northern house mosquito. Females feed at night and during the day are often found resting in egg-laying areas or near vegetation along the edges of egg-laying areas. In a study conducted by Molaei *et al.* (2007) in Texas, out of the total of adult mosquitoes collected from storm drains, landscaped vegetation at residential and commercial properties, empty lot and fields, wild brush, wooded areas, and large paved parking lots, ~95% were identified as *Cx. quinquefasciatus*. Studies conducted by Trout and Brown (2007) and Andreadis and Armstrong (2007) in Florida and Connecticut, respectively, demonstrated that CO_2-baited traps placed at the tree canopy level, compared to those placed on the ground, collected more *Culex pipiens* mosquitoes. These studies would suggest that *Cx. pipiens* prefer to rest and seek hosts in higher vegetation.

Given the association of species in the *Cx. pipiens* complex with human dwellings, and preference to rest in high vegetation, a malathion ULV use scenario that would likely result in the effective control of adult *Cx. pipiens* complex species, would include application to various

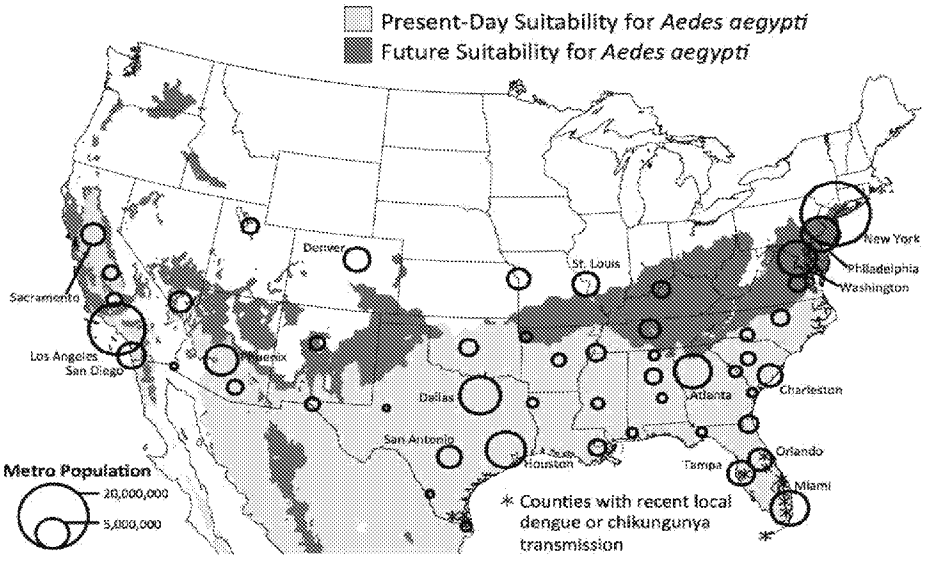
vegetative ecotones as well as near structures and dwellings. These areas would not be near habitats of endangered species that are located at very high elevations where residential and other dwellings are not established, cave-dwelling insects, and other species in locations that are sufficiently removed from locations where terrestrial applications of malathion are likely to be sprayed.

***Aedes* species**[1]

Aedes are vicious and aggressive biters and typically search for a blood meal in the early morning, and at dusk, although some are daytime biters. They prefer to bite humans and other mammals. *Aedes* mosquitoes are commonly found many miles from breeding sites.

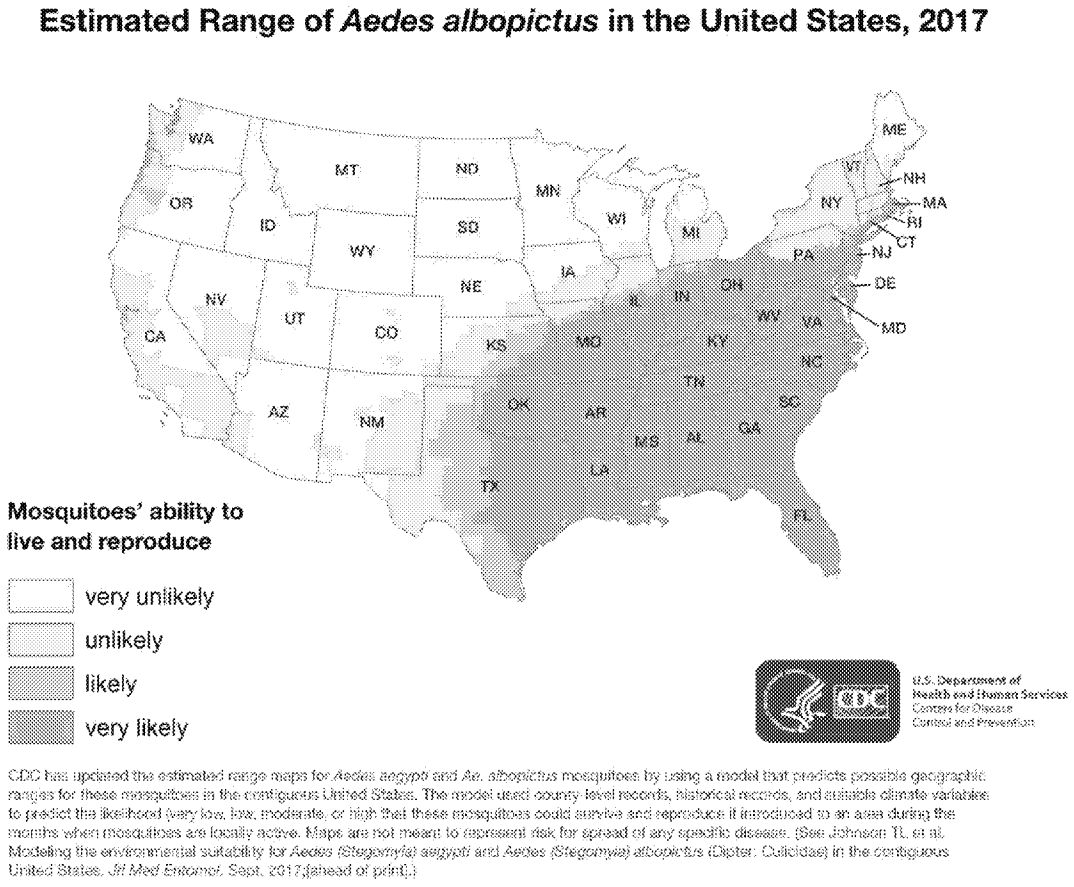
Aedes aegypti and *Ae. albopictus* (recently established in the US) are the principal mosquito vectors of dengue viruses in the US and are closely associated with humans and their dwellings. They both readily feed on blood from avian and human hosts which, combined with domestic breeding habits, make them important links between viruses and people. The distribution of these species overlap and both are common in the southeastern part of the US, with extreme ranges extending into the northeastern states (CDC, 2016, Figures 7 and 8).

Figure 7. Distribution of *Aedes aegypti* (CDC, 2017)



[1] Almost all North American species formerly placed in the genus *Aedes* were reclassified as *Ochleratatus* species by Reinert (2000). This has not been universally accepted and the taxonomy utilized herein attempts to follow the Journal of Medical Entomology. See http://www.entsoc.org/pubs/Periodicals/JME/mosquito_name_policy.htm.

Figure 8. Distribution of *Aedes albopictus* (CDC, 2017)



Studies have shown that larval competition commonly occurs; *Ae. albopictus* is typically the superior competitor (Braks *et al.*, 2004) which may contribute to the displacement of *Ae. aegypti* by *Ae. albopictus* in many parts of the US. Both species are opportunistic container breeders capable of utilizing artificial as well as natural container habitats; females lay eggs on the walls of artificial and natural containers such as in tree holes, leaf-axils of plants, open septic tanks, discarded tires, cups, bottles, and planters (http://www.cdc.gov/dengue/entomologyEcology/index.html). Eggs can withstand long periods of desiccation and larvae hatch once the eggs are inundated with water or when low O_2 tension stimulates hatching (Hawley, 1988). This makes control very difficult because even if all other life stages (e.g., adults, larvae, and pupae) are eliminated from an area, repopulation can occur as soon as containers with eggs are filled with water or stimulated to hatch.

Adult *Ae. albopictus* are outdoor day biters found in various scrub-type habitats from rural to urban environments. Adults typically do not travel more than .25 mile from breeding sites (Goddard, 2003) and rest in shady areas in shrubs near the ground (Koehler and Castner, 1997).

Adult *Ae. aegypti* are indoor day biters, typically resting in cool, dark areas such as in wardrobes, under beds, behind furniture, etc. *Ae. aegypti* prefer human blood meals and fly 100 feet to 100 yards from breeding sites (Goddard, 2003). A study conducted in Panama (Perich *et al.*, 2000) found that out of 923 resting *Ae. aegypti* collected, 85.2% were females and the majority were collected indoors on "fixed" objects (such as walls). These areas are very hard to reach with ULV applications and in fact, studies have demonstrated that single ULV applications of malathion have been ineffective at achieving high rates of adult mortality and interfering with *Ae. aegypti* oviposition (Caste *et al.*, 1999).

It seems unlikely that ULV applications of malathion would be effective in breaking the disease cycle when *Aedes* species are involved because sufficient insecticide would need to penetrate, in large enough volumes, indoor resting areas frequented by adult mosquitoes. An indoor spraying control program where pesticide is applied to resting places of these species would probably be a more important control measure for the control of *Aedes* species that vector disease in the United States.

Common Nuisance Mosquito Species in the US

In addition to targeting species that are susceptible to and can transmit pathogens of public health importance, adult mosquito control programs use adulticides to reduce the number of nuisance species when populations surpass an acceptable threshold. Typically, this involves controlling vicious biting species associated with human dwellings. Often, biting can be so fierce that development or recreational activities are avoided. Table 1 identifies common nuisance species in the US and provides adult behavior, habitat and general distribution information. This is not intended to be an exhaustive list, but identifies important species most commonly encountered in numbers that create a pest problem. Note that some of the known vector species, such as *Ae. aegypti*, *Ae. albopictus*, and *Culex* spp., are aggressive biters and can become a nuisance in large numbers. Table 2 lists specie's peak activity times and flight ranges. Be advised that while peak activity periods are listed and have been documented, species are often quite active at other times of the day when potential hosts are present.

Table 1. Common Nuisance Species in the US

Species Name	Adult behavior and habitat	Distribution[1]
Ae. squamiger	Breeds in salt marsh; females lay eggs on mud along the edge of receding tide pools; major pest species in California and can migrate up to 15 miles inland in search of a blood meal. (SMCMAD, undated)	Major pest species in California
Ae. vexans	Breeds in floodwaters and temporary freshwater in wooded and open areas; vicious biters, active	Throughout US

Species Name	Adult behavior and habitat	Distribution[1]
	at dusk and after dark and rest in vegetation. Typical flight range is 5 to 10 miles from breeding site. (Goddard, 2003)	
Ae. dorsalis	Breeds in salt marsh and most common in the summer after high tides; adults are very aggressive, capable of producing very high numbers and fly moderate distances. (ACMAD, 1999)	Western and far north US
Culiseta incidens	Breeds in temporary pools, fish ponds, and roadside ditches; commonly found in urban areas. Can produce sufficient numbers to cause discomfort; moderately aggressive and bites in the evening. Common in urban and suburban areas. (ACMAD, 1999)	Western
Ochleratatus japonicas	Breeds in containers and numbers can be great after rains; aggressive biter and has a flight range up to 600 ft. (VADH, 2005)	Northeast and Washington state
Ochlerotatus sollicitans	Breed in salt marshes; fierce biters and will "swarm" from marsh areas into neighborhoods. Rest on vegetation in day but bite when disturbed; commonly fly and bite during day. Can travel more than 40 miles from breeding site. (Gaines, 2008; Goddard, 2003)	Southeast, eastern coastal states, and isolated populations throughout central US
Ochlerotatus sticticus	Breeds in temporary flood pools in open fields or shaded locations and woodland pools; adults commonly fly and bite during day. (Gaines, 2008)	Found in all states except New Mexico, Arizona, South Florida, Southwest Louisiana, Nevada (except the far northwest corner)
Ochlerotatus taeniorhynchus	Breeds in salt marshes and freshwater pools near salt marshes; fierce biters but not very likely to bite in sunlight. Can fly up to 18 miles from breeding sites. (Gaines, 2008; Goddard, 2003)	Southeast, eastern coastal states, and isolated populations in California, Arizona, Oklahoma, Kansas, and Texas
Ochlerotatus tormentor	Woodland; temporary or seasonal woodland pools containing dead leaves. (Gaines, 2008)	Southeast
Psorophora columbiae	Breeds in temporary open fields and abundant in rice fields; Commonly fly and bite during day and can fly at least 10 miles from breeding sites. (Goddard, 2003)	Southeast and central states; southern California, Arizona, New Mexico, and Colorado

[1]Distribution information obtained from Darsie and Ward, 2005.

Table 2. Important Species Flight Ranges and Peak Activity

Species	Flight Range	Peak Activity
Aedes aegypti	200 meters	Day or night
Aedes albopictus	200 meters	Day or night
Aedes dorsalis	2-5 miles	Day or night
Aedes japonicus	300 meters	Day or night
Aedes squamiger	15 miles	Crepuscular
Aedes vexans	5-10 miles	Primarily after dark and throughout the night
Anopheles freeborni		Crepuscular
Anopheles quadrimaculatus	< 1 mile	Crepuscular
Anopheles pseudopunctipennis	1 mile	Crepuscular
Culex pipiens	1-3 miles	After dark and throughout the night
Culex quinquefasciatus		After dark and throughout the night
Culex tarsalis	17 miles	Sunset
Culiseta melanura	< 1 mile	Feeds on birds but amplifies EEE
Ochlerotatus sollicitans	40 – 70 miles	Daylight
Ochlerotatus sticticus	2-5 miles	Daylight
Ochlerotatus taenorhynchus	18 miles	Daylight
Ochlerotatus tormentor	1-3 miles	Day or night
Psorophora columbiae	10 miles	Daylight

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